Building Envelopes and Materials

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Outline

1) Identification of technical expertise and subject area
    1) Background, principles
2) Opportunities
3) Key Technical Barriers to advancement
4) Recommend Paths Forward

URLs provided at the end

Scope

- Buildings, building performance, building enclosure, building envelope
- Improved energy efficiency
  - Loose interpretation of NZE

- Marc Rosenbaum, Energysmiths, Inc.: Photovoltaics are the badge allowed to be worn by those who do everything else correctly.

Technical expertise and subject area

CHAPTER 23

HEAT, AIR AND MOISTURE CONTROL IN BUILDING ASSEMBLIES—FUNDAMENTALS

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PROPER design of space heating, cooling, and air conditioning requires detailed knowledge of the building envelope's overall heat, air, and moisture performance. This chapter provides guidance in the analysis and design of building envelope assemblies for good heat air and moisture performance. Guidance for design and sizing of mechanical systems is found in other chapters of the ASHRAE Handbook. This chapter deals with heat, air, and moisture transfer definitions; flow calculations for heat, vapor, air, and water; and the fundamentals of combined heat, air, and moisture movement as it relates to envelope assemblies.[1]

Because heat, air and moisture transfer are coupled and closely interact with each other they should not be treated separately. In fact, improving the energy performance of the building envelope may result in moisture related problems. The evaporation of water or the removal of moisture by any other means are processes that may require a considerable amount of energy which is not always available. Only a sophisticated moisture control strategy can guaranty hygienic conditions and adequate durability of modern energy efficient building assemblies. Effective moisture control design has to deal with all hygrothermal loads acting on the building envelope. Therefore a general discussion of environmental loads and their implications for the building envelope has been added at the beginning of this chapter.

TERMINOLOGY AND SYMBOLS

The following heat, air, and moisture definitions and symbols are commonly used.

A **building envelope** or **building enclosure** provides physical separation between the indoor and outdoor environments. A **building assembly** is any part of the building enclosure, such as wall assembly, window assembly or roof assembly, that has boundary conditions at the interior and the exterior of the building. A **building component** is any element or material within a building assembly.

Heat

Temperature t in °F
Specific heat capacity c is the change in heat (energy) of unit mass of material for unit change of temperature in Btu/(lb·°F)
Volumetric heat capacity ρc is the change in heat stored in unit volume of material for unit change of temperature, in Btu/(ft^3·°F)

[1]The preparation of this chapter is assigned to TC 4.4, Building Materials and Building Envelope Performance.

BSR/ASHRAE Standard 160P

Second Public Review Draft

ASHRAE® Standard

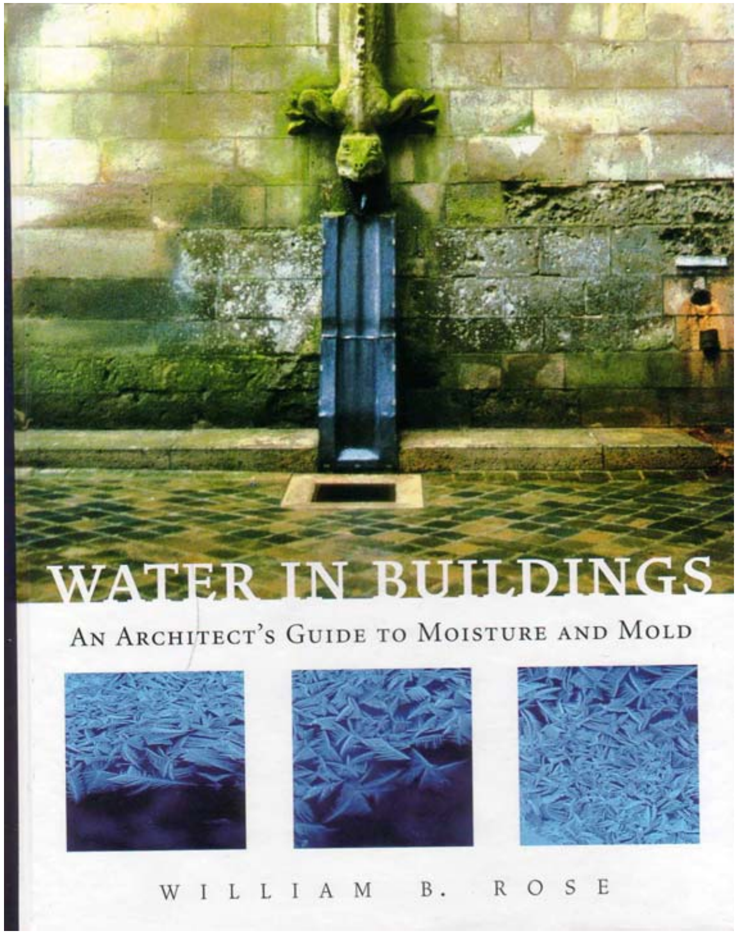
Proposed New Standard 160, *Criteria for Moisture Control Design Analysis in Buildings*

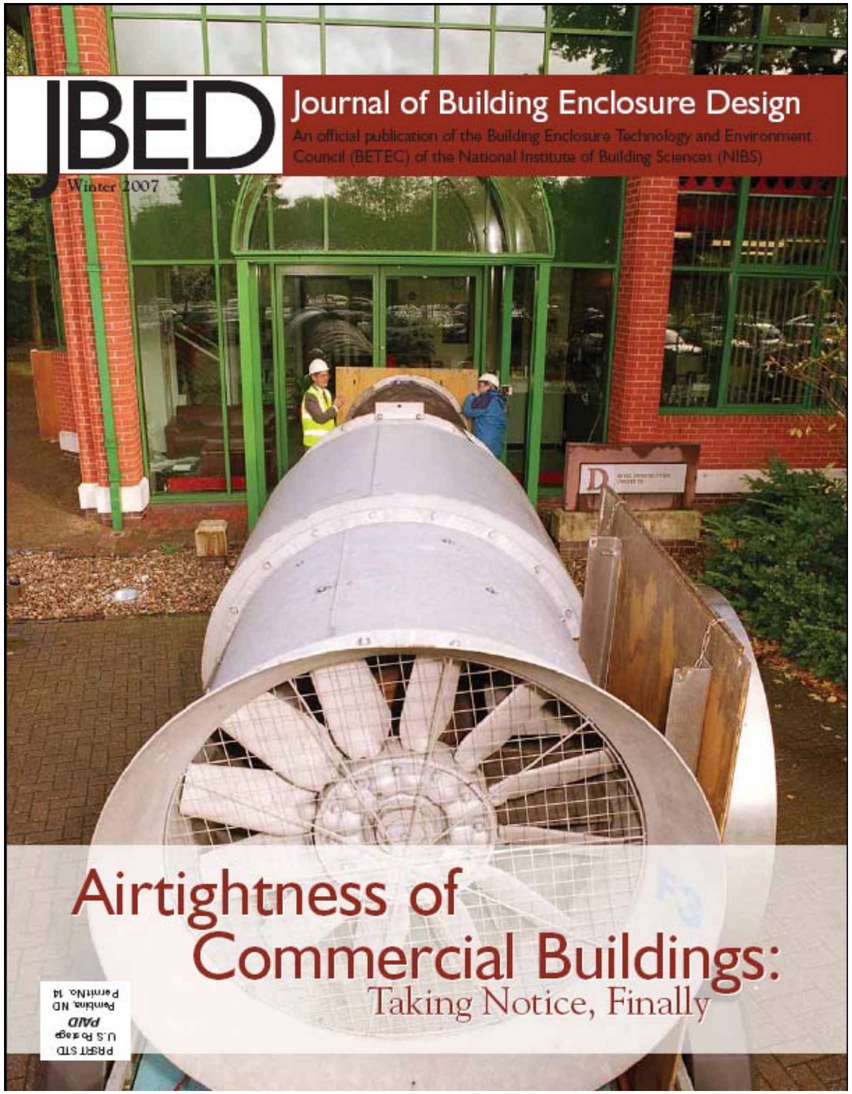
Second Public Review

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed addendum, use the comment form and instructions provided with this draft. The draft is subject to modification until it is approved for publication by the ASHRAE Board of Directors and ANSI. The current edition of any standard may be purchased from the ASHRAE Bookstore @ http://www.ashrae.org or by calling 404-636-8400 or 1-800-527-4723 (for orders in the U.S. or Canada).

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
1791 Tullie Circle, NE Atlanta GA 30329-2305

Technical Expertise and Subject Area





Background: GAO report, April 1980

PB80-1672

Federal Demonstrations of Solar Heating and Cooling on Commercial Buildings Have Not Been Very Effective

(U.S.) General Accounting Office
Washington, DC

15 Apr 80

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

FEDERAL DEMONSTRATIONS OF SOLAR HEATING AND COOLING ON COMMERCIAL BUILDINGS HAVE NOT BEEN VERY EFFECTIVE

D I G E S T

GAO reviewed the Department of Energy's program for demonstrating solar heating and cooling on commercial buildings and found that

--most projects funded under the program have not demonstrated that solar heating and cooling are practical,

--data dissemination has not been very successful, and

--the extent the program has aided in developing a viable solar industry is unknown.

MOST PROJECTS HAVE NOT DEMONSTRATED PRACTICALITY

As of July 1979, the Federal Government had spent over $44 million on 238 solar projects on commercial buildings. While these projects have provided invaluable hands-on experience for builders, installers, and others integrally involved with the program, most of the projects funded have not demonstrated that solar heating and cooling of buildings are practical--many of the projects were not operating properly and most projects were not cost effective.

Very few commercial demonstration projects were operating as designed. As of June 1979, only 104 of the 238 projects funded had been constructed and each project's related solar system started up. Of the 104 projects, 55 (or 53 percent) were either down, partially operating, or were being tested. Additionally, neither the Department of Energy nor the project owner knew how much energy many solar systems were contributing. Of those with data available, many were not providing the expected energy. (See p. 6.)

Most projects funded under the program are not economically viable. GAO's analyses showed that most projects were not expected to pay for themselves within the 3 to 5 years generally required by industry, and most projects had expected energy costs several times greater than the most expensive alternative fuel. (See p. 11.)

The program's failure to demonstrate practicality was largely attributed to the Department's lack of a definition of practicality, the absence of a strategy for supporting projects meeting that definition, and the Department's failure to emphasize cost-effective systems in choosing projects for support. Another factor was the Department's funding of projects based on sketchy design data contained in project proposals. (See pp. 9 and 14.)

DATA DISSEMINATION HAS NOT BEEN VERY SUCCESSFUL

The Department of Energy has established a data dissemination program to provide reliable, objective information to enable individuals and organizations to make decisions on the purchase and use of solar heating and cooling equipment. The data dissemination program cost for commercial demonstrations, through fiscal year 1979, exceeded $13 million. The benefits from this program thus far have been limited. Site data collection and analysis have been relatively slow, with only a few sites actually providing reportable data. Some sites will probably have no data collected. Additionally, it is doubtful that the information collected and disseminated primarily through the Department's Technical Information Center at Oak Ridge, Tennessee, is reaching much of the target audience. (See p. 20.)

EXTENT THE PROGRAM HAS AIDED IN DEVELOPING A VIABLE SOLAR INDUSTRY UNKNOWN

The Department of Energy had not translated its definition of what constitutes a viable solar industry into specific measurable

goals by which it could measure the industry's progress and develop strategies for stimulating the industry.

While the industry has grown considerably and the Department has implied in hearings and program documents that its program is generating private buying, GAO's analysis indicated the Department does not know what effects its program is having. GAO believes it is doubtful that the demonstration projects have stimulated much additional buying because most projects did not show solar energy systems to be practical. (See p. 27.)

RECOMMENDATIONS TO THE SECRETARY OF ENERGY

Because most solar projects on commercial buildings were not demonstrating that solar heating and cooling are practical and because of the large number of projects with operational problems which can serve as disincentives to the widespread use of solar energy, the Secretary of Energy should:

--Evaluate all solar demonstration projects on commercial buildings to identify the magnitude of each project's problems, what it would take to correct the problems, and the likelihood that the project will show solar to be practical. Action should be taken to correct the problems identified.

--Take specific actions to increase the likelihood of funding projects which demonstrate solar to be practical, thereby encouraging more use of solar heating and cooling. (See p. 16.)

To improve data dissemination, the Secretary of Energy should:

--Devise a means to determine the amount of energy being provided by each demonstration project. Such information is critical to evaluating the system's practicality and will also add meaning to manually collected data.

--Direct the Technical Information Center to expand its criteria for adding groups to its mailing list to ensure that more industry user groups are reached.

--Place greater emphasis on making user groups aware of the availability of data produced from demonstration projects. (See p. 25.)

Because the Department of Energy does not know whether its program is aiding in developing a viable solar industry, the Secretary of Energy should develop appropriate measurements to gauge the impact of its solar demonstrations on commercial buildings, and, if appropriate, develop alternative strategies or options, including legislative proposals, for encouraging the widespread use of solar on commercial buildings. The Secretary should present the options with probable costs and impacts to the Congress for its consideration in funding further solar programs. (See p. 32.)

MATTERS FOR CONSIDERATION BY THE CONGRESS

Even with improvements to the program, GAO questions whether the demonstrations will promote widespread use of solar. In carrying out GAO's recommendations, the Secretary of Energy may be developing and reporting to the Congress alternative strategies for encouraging widespread use of solar heating and cooling of commercial buildings and for developing a viable solar industry. To the extent such strategies include new legislative proposals, the Congress will have to carefully weigh the costs and associated impacts of each such proposal in order to decide which are best for achieving the program's intended effect. (See p. 32.)

AGENCY COMMENTS

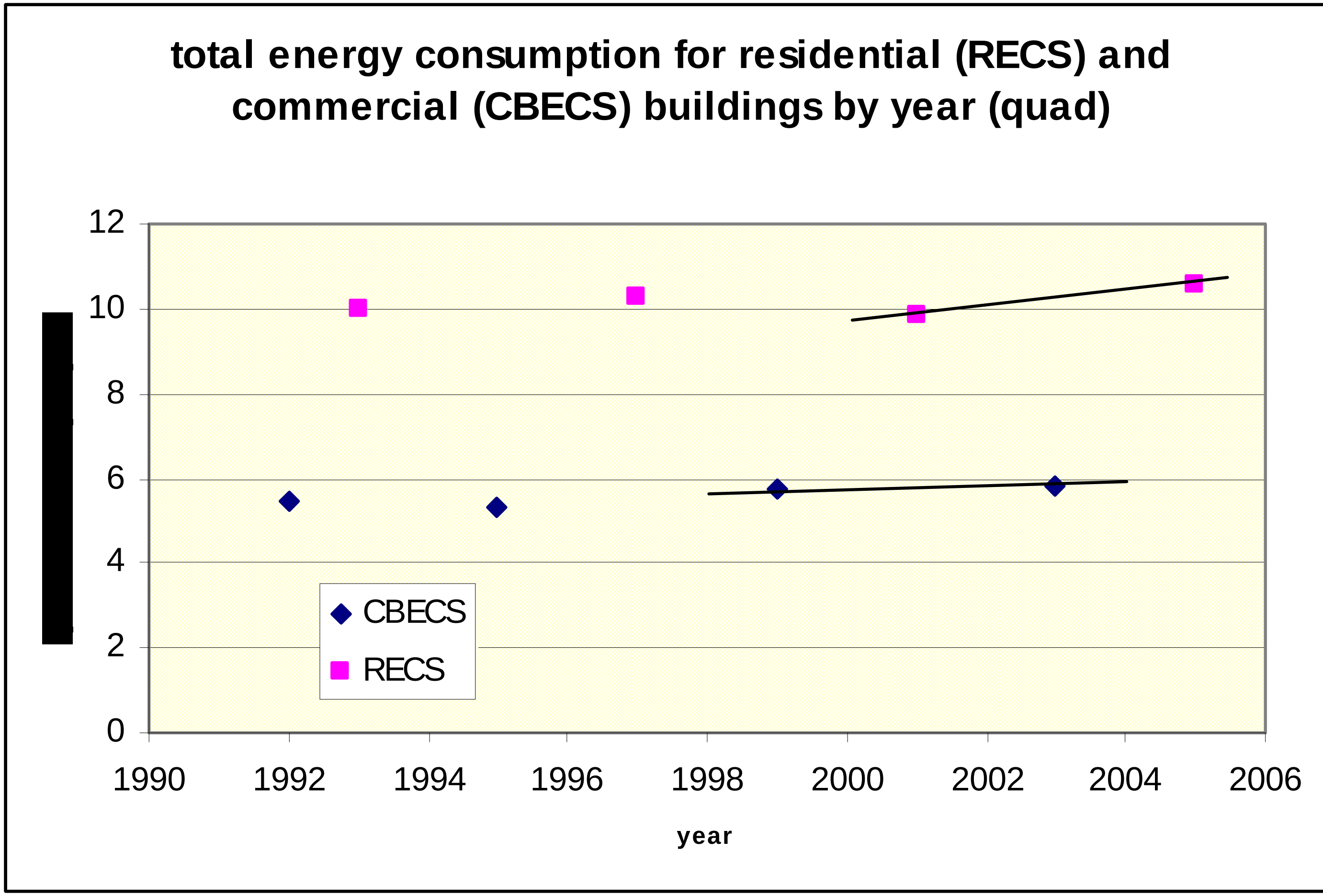
In its comments (see app. II), the Department of Energy agreed with GAO's recommendations with one qualification. In the Department's opinion, GAO's criticism of the economic viability of the demonstration

projects failed to take into account the intent of the Congress when it passed the Solar Heating and Cooling Demonstration Act of 1974. GAO, however, disagrees with the Department's interpretation of legislative intent.

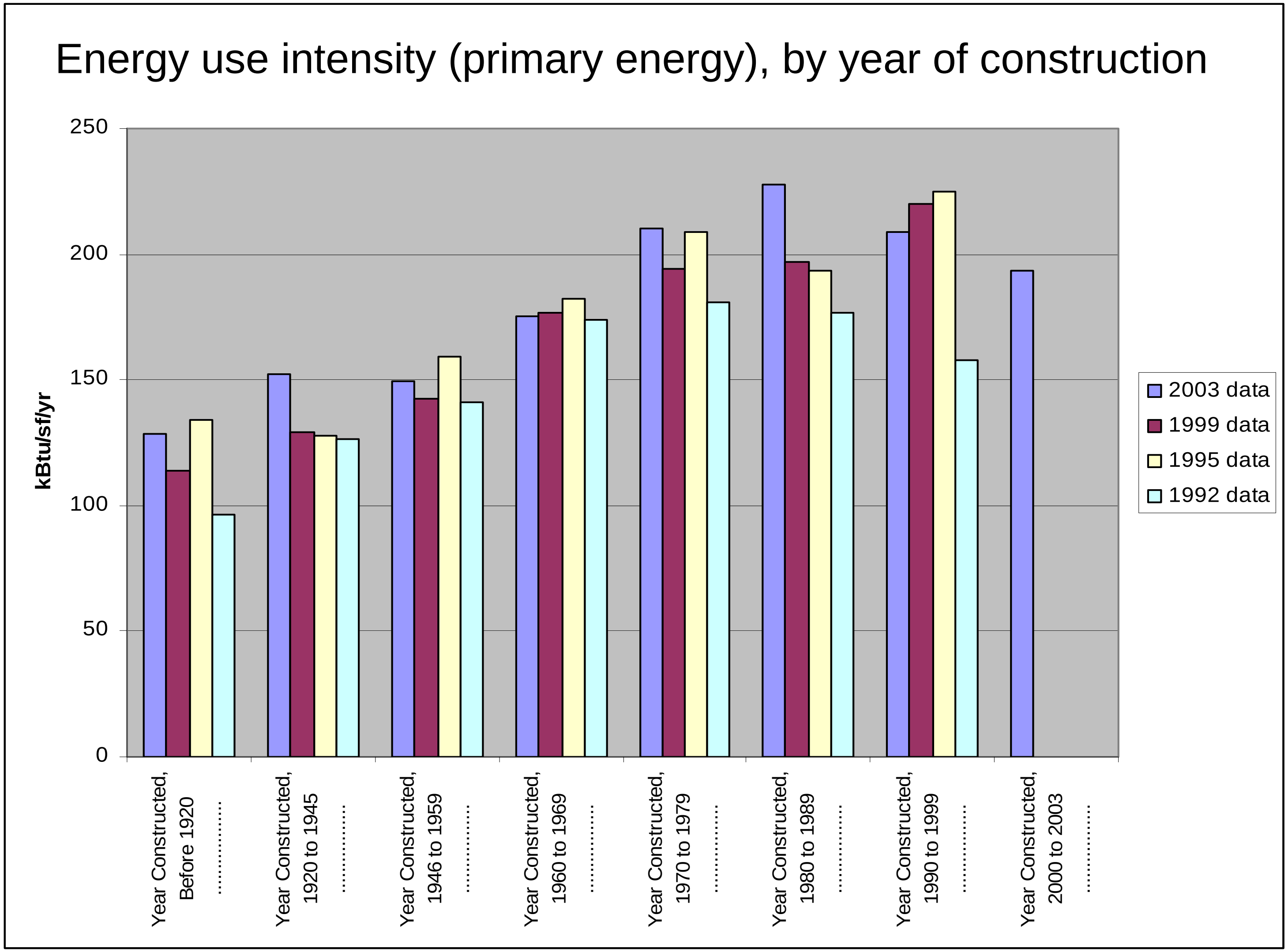
The Department also suggested three additional recommendations concerning the premature nature of the demonstrations. GAO believes it has adequately covered the thrust of two of these recommendations and disagrees with the merits of the third.

The Department's comments and GAO's evaluation are presented beginning on page 17.

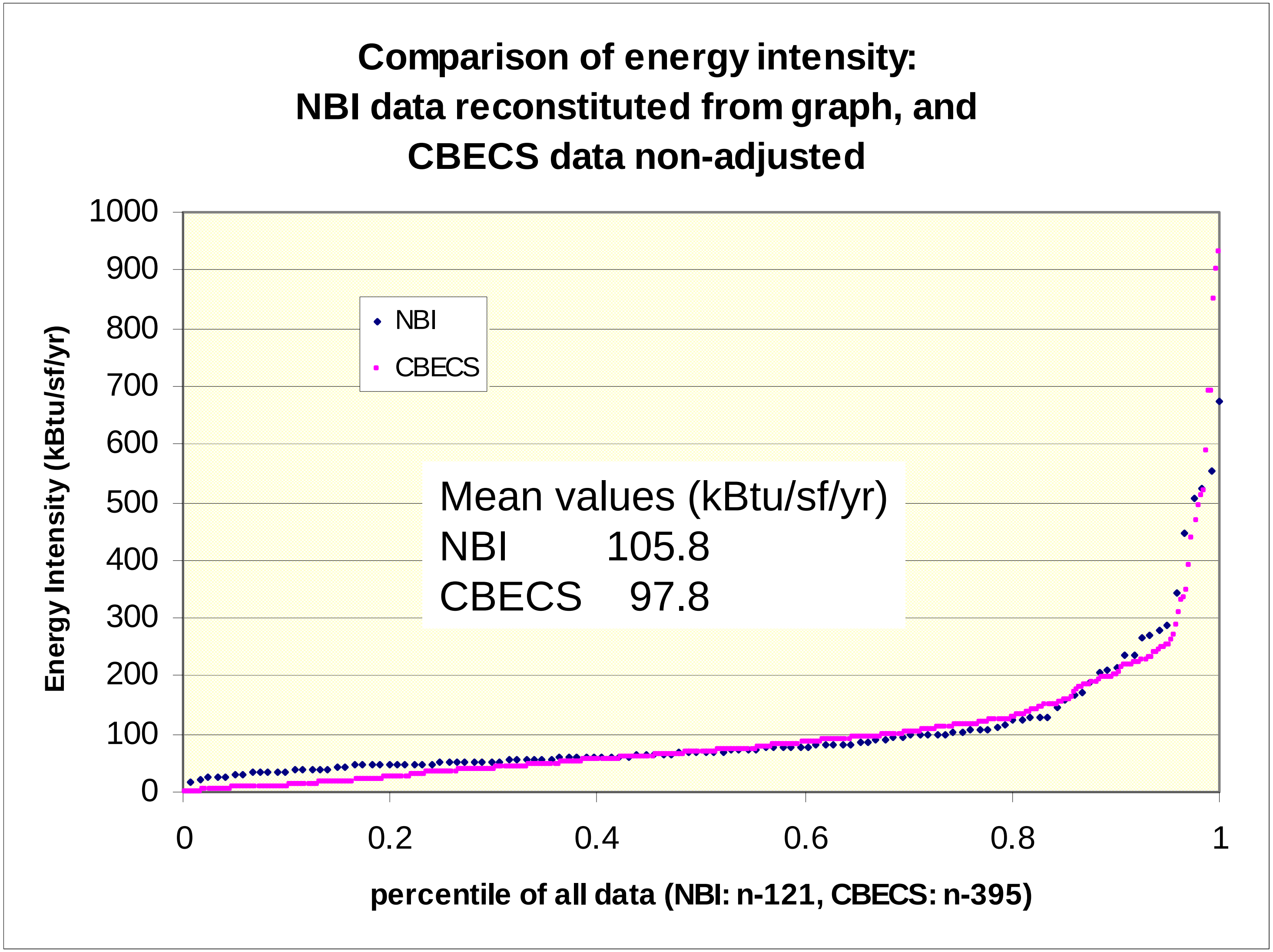
Background. Building energy use increasing



Background: Energy Use Intensity decreasing, by year of construction, four CBECS studies



Background: LEED energy use compared to CBECS



Background, summary

- Previous efforts at improving energy performance of buildings--failures?
  - IG, low-e, low-income weatherization, foams, superinsulation, energy codes, building science, appliance efficiency, ddc, air-to-air exchange,...
- On the whole, building energy use is increasing. New data may reveal otherwise.
- Energy Use Intensity in the US is decreasing.
- Programs with effective evaluation show improved energy use. Programs with low level of evaluation show disappointing energy use.

Opportunities

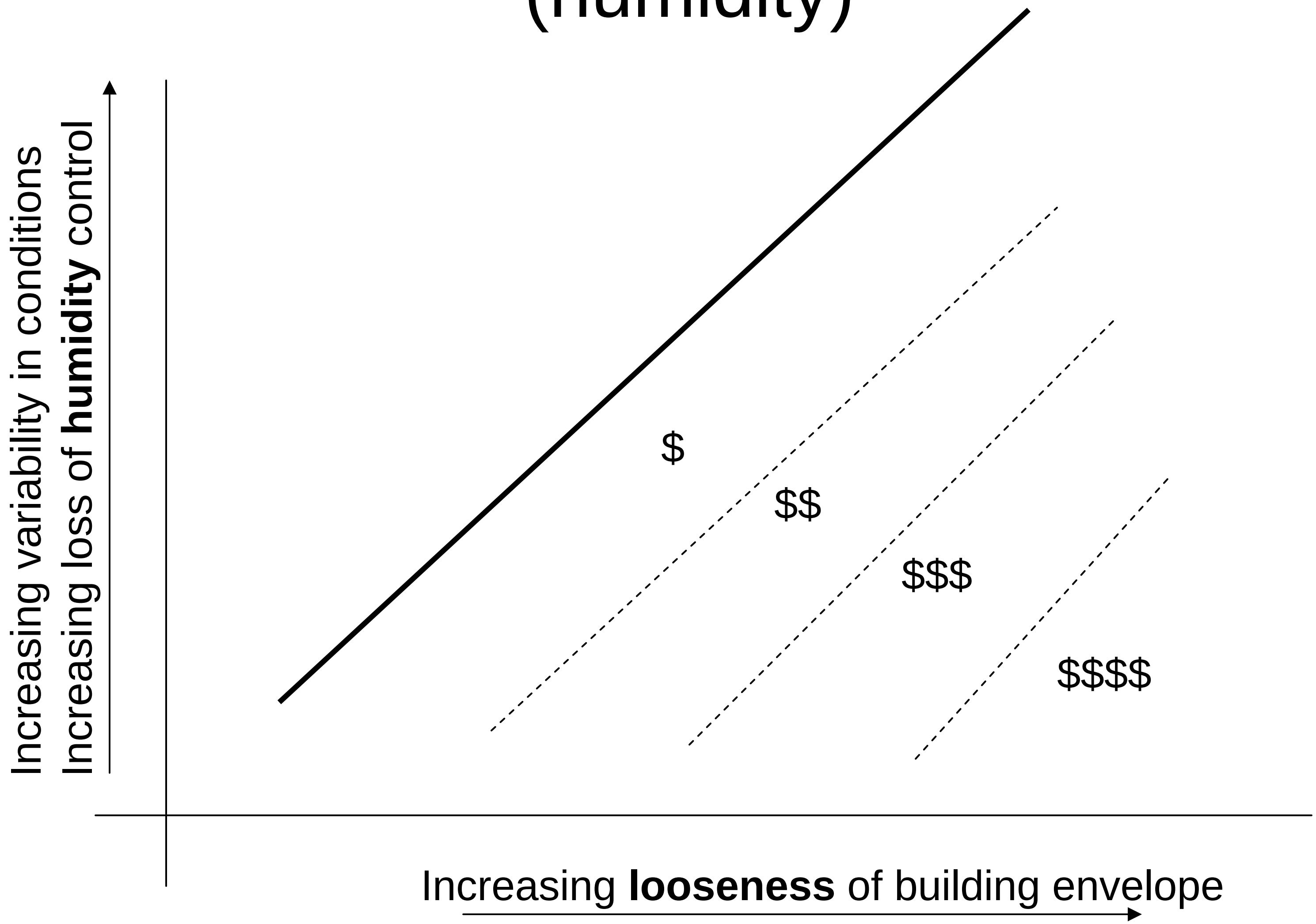
- Aim: to reduce energy use in buildings by improving the building envelope
  - Principles

- Airtightness
- Promising materials
- Not-so-promising materials
- Existing (legacy) buildings

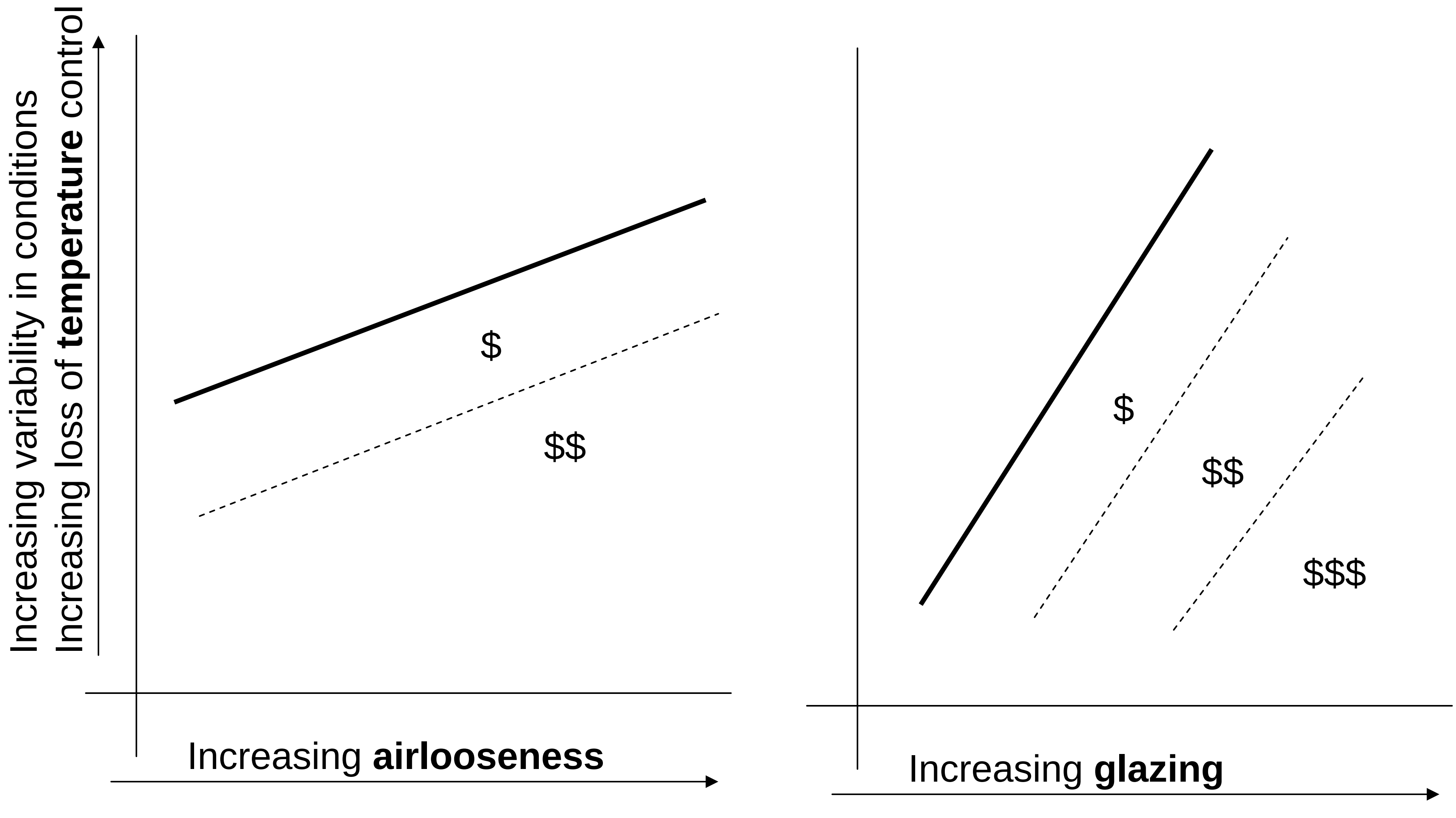
Building envelope principles

- Good roof, dry foundation
- Apply thermal insulation to the exterior
  - Assign low value to insulation in metal stud ass'y
  - Discontinuities with interior application
- Keep glazed wall percentage < 30%
- Ensure airtightness (see below)
  - Ensure continuity of insulation, airtightness **at details**.
- Durability is a function (primarily) of rainwater drainage and maintenance
- Existing buildings are rising in importance
- Standards exist to address common vapor protection questions. ASHRAE 160.
- Fund maintenance, operation, repair, replacement

Opportunities: Effect of airtightness on control and variability of interior environment (humidity)



Opportunities: Control and variability of interior environment (temperature)



Airtightness targets
http://www.nibs.org/JBED/JBED_Winter08.pdf
Terry Brennan

- British best practice for office buildings is 2 m^3/hr@50 pascals per m^2 surface area (2.6 m^3/hr or 0.72 L/s @75 pascals per m^2 surface area—assuming n=0.65) (ATTMA, BSRIA). Two of the buildings in the dataset are within 10 percent of this target, but none definitively meet it.
  - For commercial buildings Henri Fennell suggests a State of the Art target of 2.7 m^3/hr@50 pascals per m^2 surface area (3.5 m^3/hr or 0.97 L/s @75 pascals per m^2 surface area—assuming n=0.65) (Fennell 2005). Just over 2 percent of the buildings meet this target.
  - ASHRAE Addendum z to 90.1 2004 allows 2 L/s @ 75 Pa per m^2 surface area.
  - US Army Corps of Engineers airtightness requirement is set at 1.25 L/s @ 75 Pa per m^2 surface area.

Airtightness unit conversions @ (pressure) Pa

British Part L	10	m3/h-m2 @ 50	3.6	L/s @ 75	0.0059	cfm/ft2 @ 50
British normal	5	m3/h-m2 @ 50	1.8	L/s @ 75	0.0029	cfm/ft2 @ 50
British best	2	m3/h-m2 @ 50	0.72	L/s @ 75	0.0012	cfm/ft2 @ 50
Henri Fennell	2.7	m3/h-m2 @ 50	0.97	L/s @ 75	0.0016	cfm/ft2 @ 50
ASHRAE Add-z	5.56	m3/h-m2 @ 50	2	L/s @ 75	0.0033	cfm/ft2 @ 50
Army Corps	3.47	m3/h-m2 @ 50	1.25	L/s @ 75	0.0020	cfm/ft2 @ 50

Building envelope opportunities

- Foams and gels--next speaker
- Air barriers--next speaker and Air Barrier Association of America
- Low emissivity surfaces
- High quality, insulated glazing, evacuated glazing

Building envelope opportunities--not-so-hot

- Dynamic wall
- Phase change materials
- Double-wall construction
- Vacuum panels
- Thermal insulation at metal studs
- Insulating existing buildings at the interior
- Replacement windows
  - try insulated storms

Opportunities: existing buildings

- Durability studio
- Preservation + weatherization + building science + auditing
- Cultural appreciation
- Push-come-to-shove resilience
- How long should buildings last?

Barriers

- **Metering**, reporting, auditing, analysis, summary
  - Projections (models) cannot indicate variance
  - Owners resent publication of utility data
  - Tennessee example: utility data is public
  - Reluctance to do program evaluation
- **Contracting** for high performance
  - Resistance to **airtightness** standards
  - Design-bid-build delivery
  - Complaints of unavailable equipment and expertise
- **Case studies** in peer-review literature
  - Owners' reluctance
  - Control by reporting parties
  - Few venues, low standing

Paths forward

1. Improve energy reporting
2. Performance contracting
3. Tracer gas improvements
4. Building Envelope Recommissioning Center
    1. BERC lite

Path forward 1: Improve energy reporting

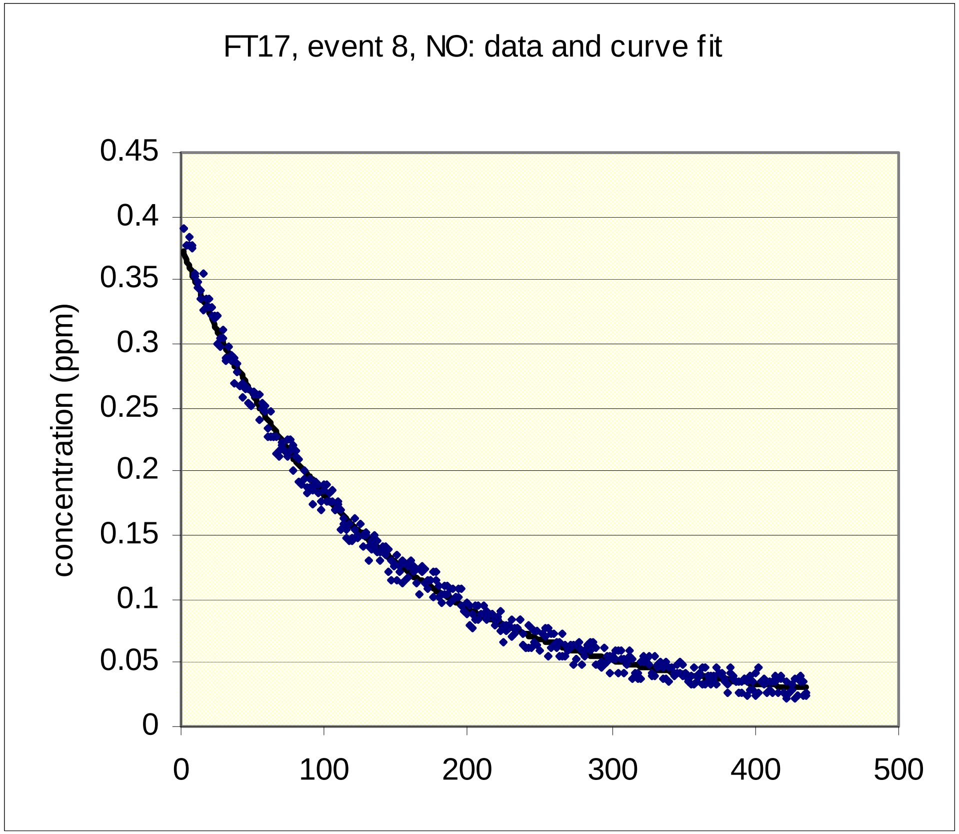
- Meter everything
- Make data available for research purposes
  - Determine variability of energy use
- Conduct program evaluation
  - Avoid reports like GAO 1980.
- Develop energy dashboards
  - Wireless data transmission from sensors
  - Provide energy conserving opportunities by web
  - Conduct pre-post retrofit studies directed from afar
  - Collect and analyze retrofit assist studies.
- Improve case study reporting.
- No excuses.

Path forward 2: Performance contracting

- Support specifications for performance, including airtightness specification
- Ensure the delivery vehicle can deliver performance
  - design-build--probably
  - design-bid-build--unlikely
- provide oversight, QA, commissioning, to ensure compliance
- find paths for correcting non-compliance

Path forward 3: Tracer gas improvements

- CO_2, SF_6, He, PFT are common. All have limitations.
- Recommend development of microtracers.
- Recommend NO.

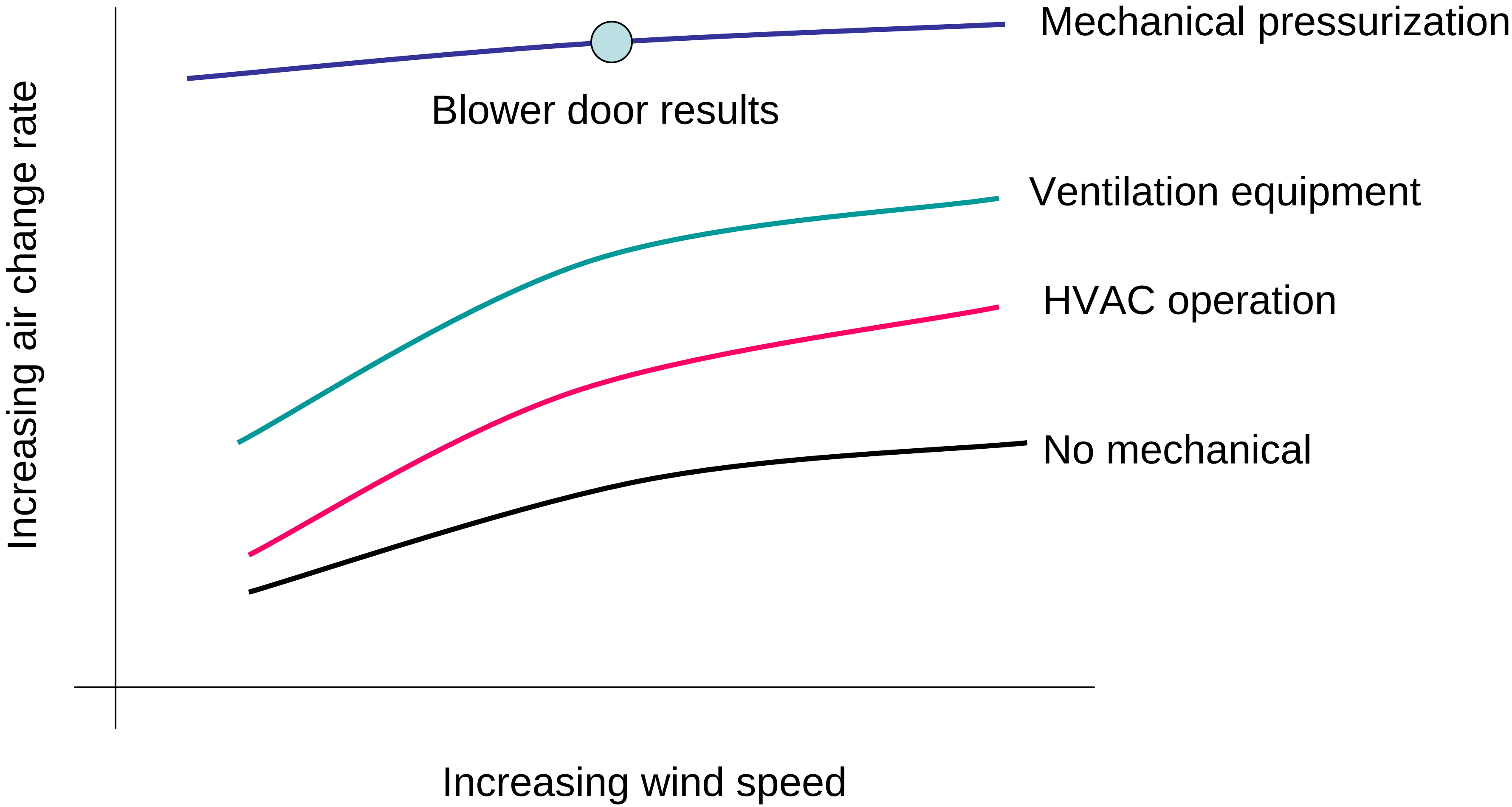


Blower door / tracer gas

- Snapshot
  - usually with one mode of operation
  - usually at one wind speed
- Simultaneous diagnostics and leak tracing
- Hole performance may be distorted by pressure

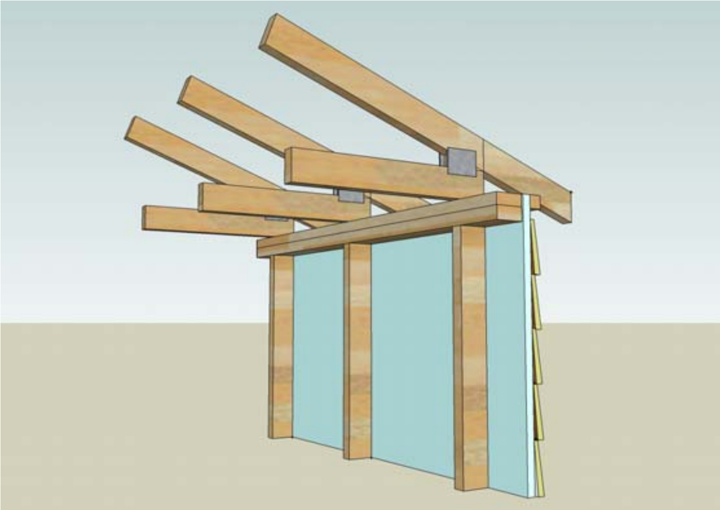
- Conducted over time
  - Various modes of operation
  - At various wind speeds
- Does not aid thermography
- Captures correct hole performance
- Gases may be troublesome

Schematic of building/envelope performance



Path forward 4: Building Envelope Recommissioning Center

- Develop a facility that houses mockups and test equipment.
  - Build full-scale bays of client buildings that include all details
  - Test, improve, retest, further improve, retest
  - Retain mockup for training
  - Ensure thermography, airtightness, water test capabililty.
- BERC-lite
  - Provide all services of full-scale mockup on particular building details (floor-wall, roof-wall, etc.)
  - Take advantage of improved 3-D graphic capability



References URL

- Journal of Building Enclosure Design (JBED) http://www.nibs.org/jbed.html
- ASHRAE Handbook, Standard 160 http://www.ashrae.org
- Oak Ridge National Laboratory www.ornl.gov
- Air Barrier Association of America www.abaa.org
- Energy Information Agency (DOE) http://www.eia.doe.gov/emeu/consumption/index.html

Questions?

RP1365: Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings

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1496: Moisture transport in construction materials and assemblies at low temperatures

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Attic Thermal and Moisture Performance

Building performance in near-ocean environments (Very high exterior moisture loads, Daily on-shore winds during warm season, small land area w/ large $ investment in structure)

Investigation of long-term performance of sheathing membranes under different cladding types (issues of surfactants chemical attack, aging through testing)

Measurement of High Temperature / high humidity material properties

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Building foundations: heat & moisture transfer

Rain load on envelopes -- deposit, run-off, concentration, leakage, good detailing

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Interactions between the envelope and HVAC systems with improved air barrier effectiveness

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Effect of airflow on moisture/thermal behavior of frame walls

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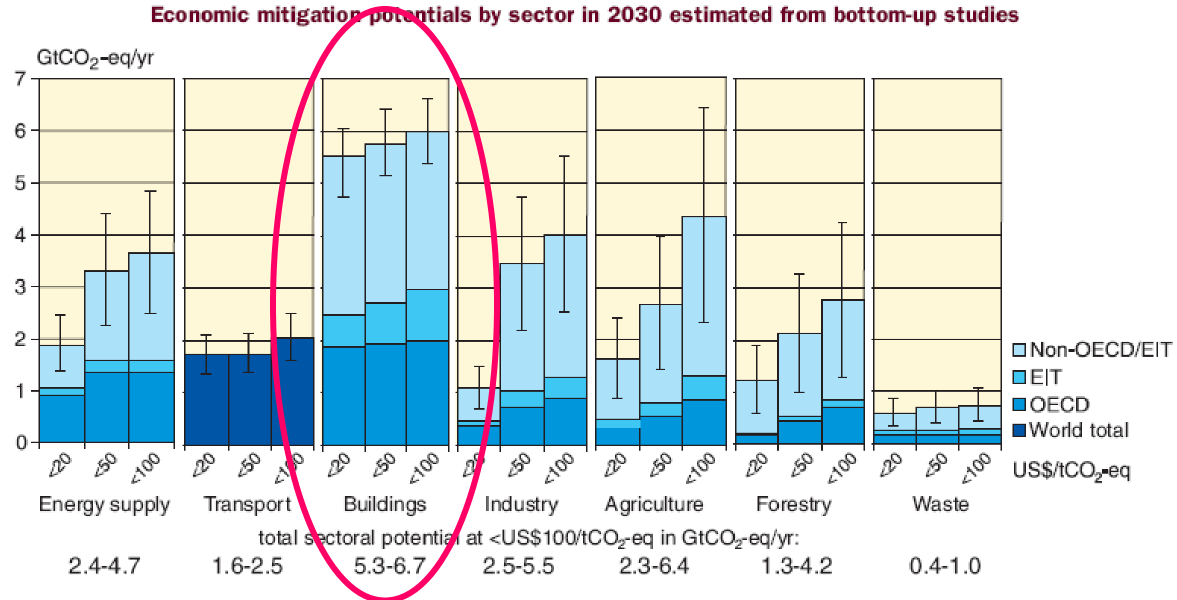
Determine thresholds for the risk of moisture damage/mold growth of various celluolse based sheathings. How much wetting ang drying is acceptable.

1018 Update: Hygrothermal properties of more common North American Materials

Impact of air tightness of 2 wall systems of a function of 5 pathways in all IECC zones
Improving thermal and moisture performance of existing residential above grade walls
Energy performance of unvented and cathedralized attics
Development of Rational test methods for water resistance of sheathing membranes based on in-situ conditions of installed barriers
Moisture production rates in multi-family dwellings
Wind-driven rain on multi-family dwelling
Improving envelope performance of historic buildings
Effect of reflective steep (sloped) roofs on moisture performance
Influence of poor workmanship
Moisture performance of details (claddings, flashings, wall penetrations, etc.)
In-plane performance/long term durability of spray polyurethane foam isulation in residential and commercial buildingsin-place
PV/Roofing integraton
Low-cost techniques for low-income zero-energy housing
Indoor Design Conditions for Moisture Design in Air-Conditioned Residential Buildings
Development of hygrothermal design guidelines for crawlspace modeling

Considerations for retrofitting wall and ceiling assemblies by climate zone
Do white roofs cause moisture problems?
Effects of sealing techniques for wall penetrations on moisture and thermal transfer
Quantification of ventilation rates behind claddings
Impact of increasing energy performance expectations on durability of envelopes
Implications of part-load performance of HVAC systems on the building envelope
Failure criteria for building materials
Improving thermal and moisture performance of existing crawlspaces
Improving thermal and moisture performance of existing basements
Thermal and moisture performance of roof assemblies with varying vapor drives
Thermal and moisture effects of insulation type and location in walls
Performance & limitations of peel & stick membranes used as water-resistive barriers in exterior wall assemblies

Economic mitigation potential, including Buildings sector



Organization for economic cooperation and development (30 countries)

Economies in transition (10 countries)

Figure 4.2. Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. {WGIII Figure SPM.6}

Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
c) Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
d) Only global totals for transport are shown because international aviation is included.
e) Categories excluded are non-CO_2 emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

Background: Pre-WW2

Figure 1-11. Research Residence No. 1, with an unusually large number of single-pane windows and six rooms with three exposed walls, was a real challenge to heat.

shown that soot leaking through windows and doors was reduced, walls and ceiling surfaces were warmer, floors were warmer, outside noises were eliminated, and a great deal of the load on the furnace was removed. If the heat loss of a house is materially reduced, it is obvious that the furnace will not have to be forced as much in order to heat the house, and that, as a result, the life of the furnace should be prolonged. If, as a result of reducing the heat load on the furnace, it is possible to avoid prolonged periods of high intensity firing, to that extent also will the fire hazards resulting from overheated smoke-pipes and chimneys be reduced.

Case	Insulation		Weather Strip	Storm Sash	Calculated Hourly Heat Loss in Per Cent of Maximum Rate (0 20 40 60 80 100)	Reduction, %
	Wall	Ceiling				
a	None	None	None	None		0
b	1-in.	None	None	None		12.8
c	2-in.	None	None	None		17.4
d	3-in.	None	None	None		[illegible]
e	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
f	None	1-in.	None	None		11.3
g	[illegible]	[illegible]	None	[illegible]		13.5
h	None	3-in.	None	None		[illegible]
i	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
j	3⅝-in.	3⅝-in.	None	None		34.8
k	None	None	Yes	None		5.8
l	None	None	None	Yes		31.3
m	3⅝-in.	3⅝-in.	None	Yes		66.1

CALCULATED HEAT LOSSES OF TYPICAL RESIDENCE

3+ inches of insulation leads to 35% reduction in heat loss.
Storm sash provides 32% reduction.

“Save Fuel for Victory”

First: storm doors
Second: storm sash
Third: insulation

IV. HOME INSULATION

Seichi Konzo*

No more effective way exists of reducing fuel consumption than by applying storm windows, storm doors, and adequate insulation to the ceiling and sidewalls of a house. These items can be considered as equivalent to an "overcoat" for the house.

The first "must" requirement for adequately protecting the house is the use of storm doors. In an average house, about four to five per cent of the heat lost from the house is through and around the door. Hence, if by ap

this loss about one-h

three per cent. This su

sider the returns on th

door, it seems a most

If you are renting y

door, you should cons

stripping to the door,

air whistles through the cracks. Felt stripping sufficient in length to weatherstrip a door may be purchased at a hardware store for about ten or fifteen cents. These strips can be readily tacked on to the door frame so that when the door is closed a fairly tight seal is made. This type of weatherstripping is not as effective as a tightly-fitting storm door, but is better than none at all.

The second "must" requirement is the application of storm sash to the windows. Tests made in the Warm-Air Heating Research Residence at the University of Illinois have shown that when tightly-fitting storm sash was applied to all the windows in a house, a saving in fuel consumption of about twenty per cent was obtained. The storm sash should be tightly fitted and should be drawn up tightly when closed. It should be realized that a properly-installed storm sash not only reduces the heat transmitted through the glass, but also reduces the air leakage around the windows. With tightly-fitting storm sash it is not necessary to have separate weatherstripping attached to the inside windows. If necessary, felt stripping can be tacked on the storm sash to seal any cracks between the storm sash and the window frame. If, on account of the expense involved, all of the windows cannot be protected at one time, at least those windows which face the north and west should be protected. Other storm sash can then be added later.

*Special Research Associate Professor of Mechanical Engineering, University of Illinois.

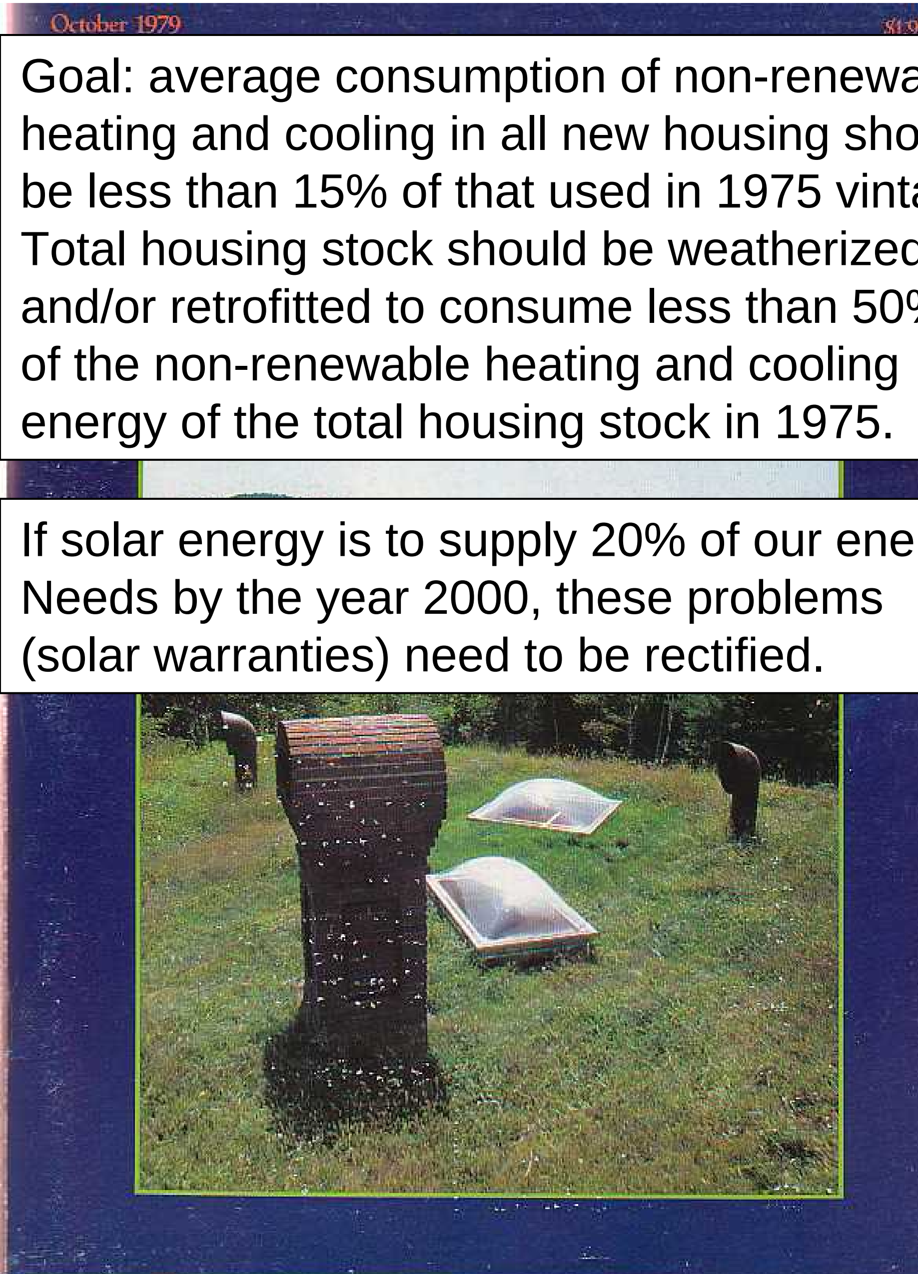
Storm sash also increases comfort. If you place a thermometer on the window sill you will find that the temperature of the air rolling off the cold window surfaces will be considerably lower than the temperature of the air in the middle of the room. When storm sash is applied to the window, the quantity of cold air that rolls down the window is reduced and the temperature is increased. This cold air that rolls off the window settles to the floor. Tests have indicated that by the use of storm sash the air temperature at the floor level, or the crawling level for a youngster, is increased two or three degrees in cold weather. In addition to raising the temperature at the floor level, the use of storm sash raises the temperature of the glass surface which faces the occupant, and thereby reduces the radiation of heat from the human body to the cold surface. Probably most of you have noticed that windows protected with storm sash do not condense moisture, or "fog," as readily as unprotected windows. This is further evidence of the fact that the inside glass temperature has been raised. An additional benefit that accompanies the use of storm sash will be appreciated by the homeowner. To a very large extent the soot that comes in around the ordinary window can be stopped by the double seal, so that in a sooty neighborhood it will no longer be necessary to dust off the soot that otherwise collects on the window sills. Taking all these benefits into consideration it appears that money invested in storm sash pays rich dividends.

The third "must" requirement is the use of insulation in the attic floor. We recommend that over the ceiling lath that is exposed in the attic, a layer of asphalt-treated paper be laid. This paper is technically known as a "vapor barrier," and serves to prevent moisture from leaking through the plaster and collecting on the underside of the roof covering. Some of the insulation that is available on the market comes in the form of a roll about 14 inches wide and from 1 to 4 inches thick, and is covered on one side with a "vapor barrier." This side of the roll or batt should be applied next to the lath. If a loose form of insulation is to be used, the insulation should be poured out of the bag and should cover the vapor barrier to a uniform depth. In any case, whether the roll form or the loose form of insulation is applied, we recommend that at least a two-inch thickness be used, and preferably a four-inch thickness. In the case of an unfinished attic floor it is also possible to nail insulating boards over the attic joists. These insulating boards are usually available in thickness of from ½ to 1 inch, and can be readily handled by any homeowner. If the attic is partly floored it may be necessary to lift up the flooring to apply the

Solar Age magazine, led to superinsulation

Goal: average consumption of non-renewable heating and cooling in all new housing should be less than 15% of that used in 1975 vintage. Total housing stock should be weatherized and/or retrofitted to consume less than 50% of the non-renewable heating and cooling energy of the total housing stock in 1975.

If solar energy is to supply 20% of our energy Needs by the year 2000, these problems (solar warranties) need to be rectified.



EDITOR'S NOTE

A Goal for Energy Efficiency Housing

...arations of energy wars ...oil import quotas have ... little to raise the energy ...ency of new buildings. ...entional energy-wasteful ...lings are still the norm in ...onstruction industry, ...r than the exception. ...is situation is particularly ...lling because several ...sand houses have been ...ing their owners cozy over ...ast five years using less ... 15 percent of the fuel ... by conventional housing. ...t, multi-pane windows ... thickly insulated walls ...ceilings provide greater comfort than conventional construction. The proper mix ...f south glass and other pass...ve systems adds airiness and ...adiant warmth. In concert ...ith energy-efficient passive ...esign, active systems can eli...minate autumn and spring ...uel bills and reduce the noise, smell, and expense of back-up systems in the coldest months. Underground construction brings this sequence one step closer to the goal of totally eliminating fuel bills by protecting the house from mid-winter extremes.

Most of these solar age homeowners have solved the first-cost problem and find that owning and operating their low energy homes—including mortgage payments, insurance, property taxes, maintenance, and fuel bills—costs less than owning conventional houses. After all, for most people, the point of saving energy is to reduce survival costs.

Energy planning for buildings should examine savings in light of total annual costs. Federal energy standards for buildings should not be developed in the absence of tax reform, new financing mechanisms, and additional mortgage money to enable building owners to prefer higher first-costs over energy inefficiency.

With today's mortgage terms, each increment in cost of $1,000 means roughly $100 more in annual mortgage payments. A $5,000 to $10,000 additional first cost for energy-saving construction can reduce annual heating (and cooling) bills by 85 to 90 percent, or $500 to $1,500, depending on construction techniques and climate.

Our 80 million buildings consume between 36 and 40 percent of our nation's energy. The oil equivalent of this consumption is 14 million barrels per day (mbd), compared with oil imports of less than 9 mbd. An $88 billion synfuels program will, at best, provide only 2.5 mbd by 1990. Energy wasteful buildings are an untapped oil reserve.

If we believe there is an energy problem, then let us stop building energy hogs. Instead, let us set a goal and establish programs to meet it: *by 1985 the average consumption of non-renewable heating and cooling energy in all new housing should be less than 15 percent of that used in housing of 1975 vintage; and the total housing stock should be weatherized and/or retrofitted to consume less than 50 percent of the non-renewable heating and cooling energy used in the total housing stock in 1975.*

Bruce Anderson
Executive Editor

ANOTHER OPINION

By Albert Gore, Jr.

Solar Warranties Badly Needed

While the Solar Age fast approaches, major problems facing consumers of solar equipment are being neglected. The level of consumer confidence in solar systems used for space heating and cooling and water heating is not very high.

Many sytems are not properly installed or sized and already have or will have problems. Furthermore, many solar consumers are not being offered warranties. Those who manage to obtain coverage are sometimes given separate warranties on the various components of a system and its installation, creating confusion in determining the liability of the manufacturers and the installer.

If solar energy is to supply 20 percent of our energy needs by the year 2000, these problems must be rectified. The actual and perceived risk in buying a solar system must be reduced to a minimum.

In order to reduce this risk, a wide range of programs should be actively supported. Consumer information should be more widely disseminated and training programs for installers expanded. Data on the performance and reliability of components and systems must be improved and new standards developed.

However, none of these efforts to help ensure system reliability and consumer confidence will be sufficient if adequate warranties are not available. Warranties are crucial marketing tools which can greatly increase consumer confidence.

Many newer solar companies are not financially able to provide comprehensive warranties. Furthermore, many companies cannot obtain insurance on their warranty policies because they may not be eligible or the insurance may be too costly.

For these reasons, I am advocating legislation which would provide government assistance in providing comprehensive warranties. Several proposals being considered include: (1) a reinsurance program which would transfer to the government part of the liability of covering solar warranty insurance policies, thereby broadening eligibility for the insurance and reducing the costs; (2) a reimbursement program which would provide financial assistance to solar companies for their insurance; and (3) a warranty insurance program which would provide supplemental assistance to solar companies to partially subsidize coverage costs and would offer back-up coverage to consumers for reasonable claims when a company participating in this program is unable to pay.

Albert Gore, Jr., is a member of Congress representing the Fourth District of Tennessee. He serves on two energy subcommittees of the Interstate and Foreign Commerce Committee and The Committee on Science and Technology in the House of Representatives.

Superinsulation and airtightness

The Art of the Possible in Home Insulation

By David A. Robinson

Annual fuel bills of less than $100 may be possible in houses that cost only $1,500 to $3,000 more to build. The economics of intensively insulated structures appear very attractive.

The residence in Northfield, Minn., was designed to be as economical as possible. Life-cycle costs were considered at the earliest stage. The method quickly led to the conclusion that greatly increased insulation levels would save money in the long run.

On an annual basis, about 70 percent of the space-heating load is met by solar energy and internal heat for the 1,800-square-foot house. Direct gain from 90 square feet of double-glazed south windows, plus internal heat, account for about 30 percent of this. The remaining 40 percent is provided by a 350-square-foot water circulating drain-down active system. Night window insulation is not used. Intensive insulation and other conservation strategies enabled only 800 kWh of electric back-up and one-half cord of wood to keep the house comfortable through the second most severe winter in Minnesota history.

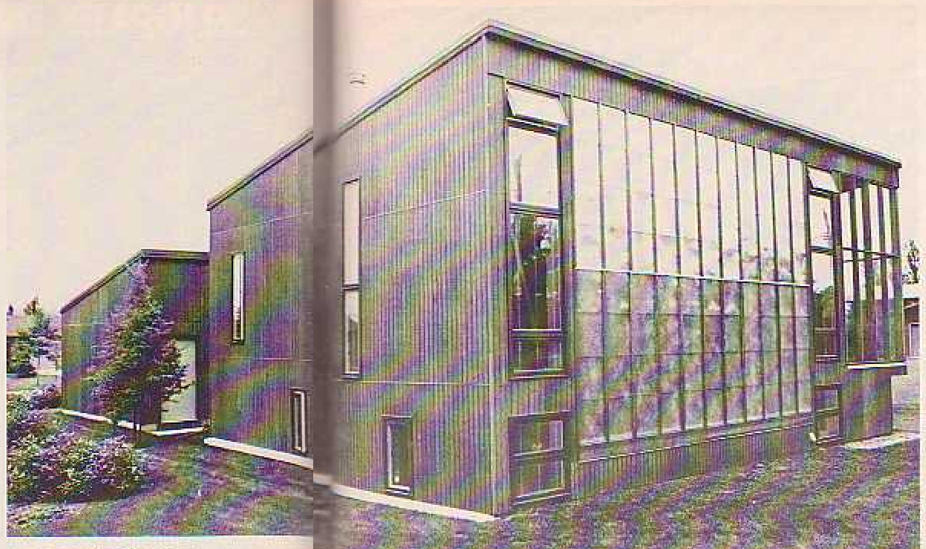
David A. Robinson is senior scientist at the Mid-American Solar Energy Center, 1256 Trapp Road, Eagan, Minn. 55121. The architect for the Northfield house was Robert Quanbeck, principal with Sovik Mathre Sathrum Quanbeck in Northfield. The general contractor was Dallas Haas of Farmington, Minn.

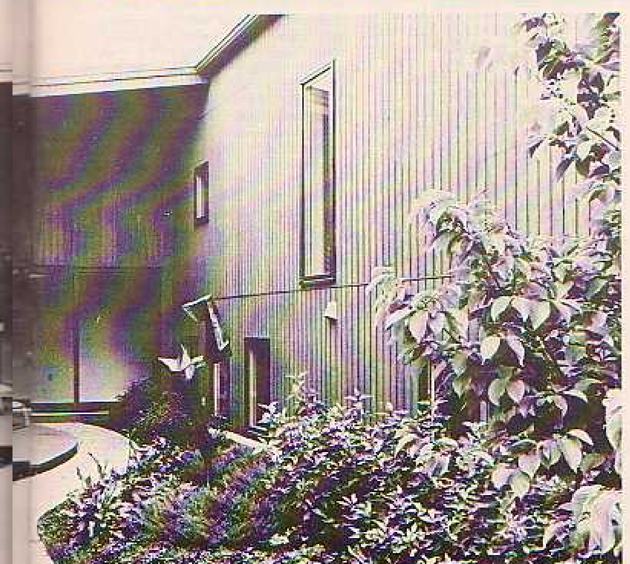
Design features

The house is oriented to take advantage of all the seasons Minnesota has to offer. A screened porch on the southeast corner receives bright morning sun in the summer and is shaded by mid-afternoon. A long entrance way serves as an air lock winter entry and a breezeway for the summer porch. Sliding glass doors to the porch and courtyard are adjusted according to seasons. The west-facing courtyard provides sunlit shelter during the fall and spring afternoons.

The total window area is about 10 percent of the floor area of the house. Half of the window area is on the south side. The remaining 90 square feet are distributed around the house to provide light, ventilation, and views without regard to climatic effects. Single-width casement windows were installed with sills near the floor line to create a desirable and pleasant illusion of space using a minimum area of glass.

Four-season air circulation is provided by a central forced-air electric furnace. An air return located near the ceiling of the upper level collects the warmest air, which is circulated to the lower level or exhausted to





the outside, depending on the season. Ducts between the levels of the house recirculate warm air in the winter and allow the whole house to be ventilated through the lower-level windows in the summer.

Insulation economics

The insulation analysis used to design the house assumes that:

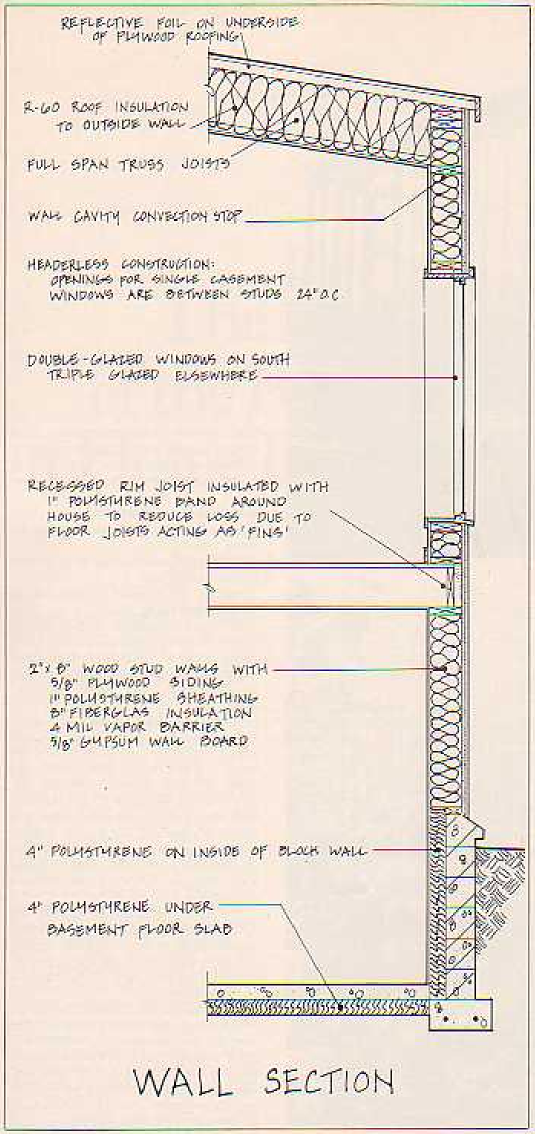
- insulation costs increase in proportion to the R value; and
- energy use decreases in proportion to the inverse of the R value.

This "simple things first" method leads to two general guidelines: *First*, the amount of money spent on a heated envelope for all insulating elements (including windows) should be equal to the present value of all money spent on space heat (solar plus back-up), if minimum total cost is to be achieved over any life-cycle period. *Second*, whether or not the optimal envelope (given by the first guideline) is used, insulation R values for each element (including windows) should be scaled in proportion to each other as the inverse of the square root of their cost per unit area per unit R value.

(The development and use of these rules are discussed in the proceedings of several solar meetings. Copies are available from the author.—Ed.)

The main result of using these guidelines for the Minnesota house was the conclusion that all insulation values should be doubled compared with current practice for even inexpensive gas heat, if a 28-year life-cycle period were chosen.

The amounts of insulation that can be added economically are very large. The sum that can be invested in insulation is equal to approximately 28 times the annual fuel bill (according to the first guideline). The exact amount depends on detailed economic assumptions, but this amount is felt to be conservative. (See sidebars.)



Energy saving features

The house was insulated as shown in Table 1. The additional insulation increased the cost of the house about $1.00 per square foot of floor area.

The direct thermal conduction paths provided by the cement block foundation and the wooden framing of the house were reduced. Window headers were eliminated by placing single casement windows directly between the studs (24 inches on center), and using 2-inch by 8-inch lumber as nailers at the top and bottom to complete a framing box to receive the window. The rim joist between the lower and upper levels of the house was recessed 1 inch around the entire house, so an additional inch of polystyrene could be added to reduce the edge losses of the upper-level floor.

The foundation block was insulated on the inside so that the interior wall of the lower level, which extends just below the frost-line (about 3 feet), would be insulated from near freezing temperatures at the footing. This decision was based on data indicating that there are about 4,500 heating degree-days per season at the depth of the footing in undisturbed soil and that cement blocks are good enough thermal conductors to cause an uninsulated wall to act as a fin, which would conduct heat out of the structure and into the earth.

Roof trusses that allowed full depth ceiling insulation to the outside of the exterior walls of the house were chosen to provide minimum conduction losses at the ceiling-wall corners of the house. The wall-wall corners were framed using only a single stud so that these corners could be filled with fiberglass insulation.

Air infiltration was reduced by carefully sealing electrical and plumbing runs penetrating the shell of the house. A notable exception to sealing detail was the conventional installation of standard electrical outlets throughout the house. Window frames were sealed using a portable kit to apply polyurethane foam between the windows and the house framing. A 4-mil polyethylene vapor barrier was installed on the warm side of the exterior walls, but no special attention was given to maintaining its integrity. The house was sheathed with tongue-and-groove polystyrene and further sealed by the application of 4-foot by 8-foot sheets of exterior plywood siding.

Windows were chosen for their low infiltration characteristics, and exterior doors were equipped with magnetic seals.

Performance results

By observing the running time of the electric furnace, the heating load of the house was measured at midnight on several −20°F evenings to be 4,100 Btu per degree-day, or 2.3 Btu per ft² per degree-day.

The average heating load was calculated using monthly values for energy use and degree-days. The average load during the first winter was found to be 2,870 Btu per de-

The infiltration rate of the house was also examined using a pressurization test, which measured the number of air changes per hour when the house was pressurized to 50 pascals (.20 inches of water). Swedish standards for this test limit the air leakage rate to three air changes per hour. This standard is generally viewed as a difficult one. However, the Minnesota house had a leakage rate of less than 1.8 air changes per hour, indicating that the Swedish standard is an accessible goal for good building practice in the United States.

During the first winter in the house, the low infiltration rate allowed an accumulation of water vapor. A dehumidifier was required thoughout the first heating season to control window condensation. During the second heating season, an air-to-air counterflow heat exchanger was used successfully to control the accumulation of moisture and to ventilate the house. The heat exchanger provided about .2 air changes per hour and was turned on for about two hours each morning and evening. The heat exchanger typically provided 80 to 90 percent of the heat required to warm the incoming flow of fresh air for a 40 to 50 percent relative humidity in the house. The two fans on the heat exchanger require a total power of about 250 watts. The total monthly operating cost is about

Leakage rate: less than 1.8 air changes per hour at 50 pascals.

straight lines, which are described by various costs of insulation and energy respectively. *(Sets of curves for incremental insulation costs of up to $10/ft² – R and papers discussing the theoretical basis of these curves are available from the author.)*

The energy lines are described by the energy cost factor (ECF) defined as follows:

ECF = (7.03 × 10⁻³) × [cost of energy ($/kWh)]
× (degree days) × (discount factor),

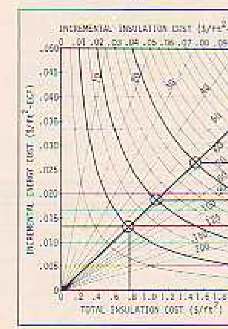
where discount factor is

$$\text{Discount factor} = \frac{1-\left(\frac{1+i_f}{1+i_d}\right)^{-n}}{i_d - i_f} \quad (i_d \neq i_f)$$

$$= \frac{n}{1+i_f} \quad (i_d = i_f)$$

Here i_f is the fuel inflation rate for future energy payments, which are discounted at the rate of i_d.

degree-days) × (26 years/1.1) = 57.3



Cloudy sky effect

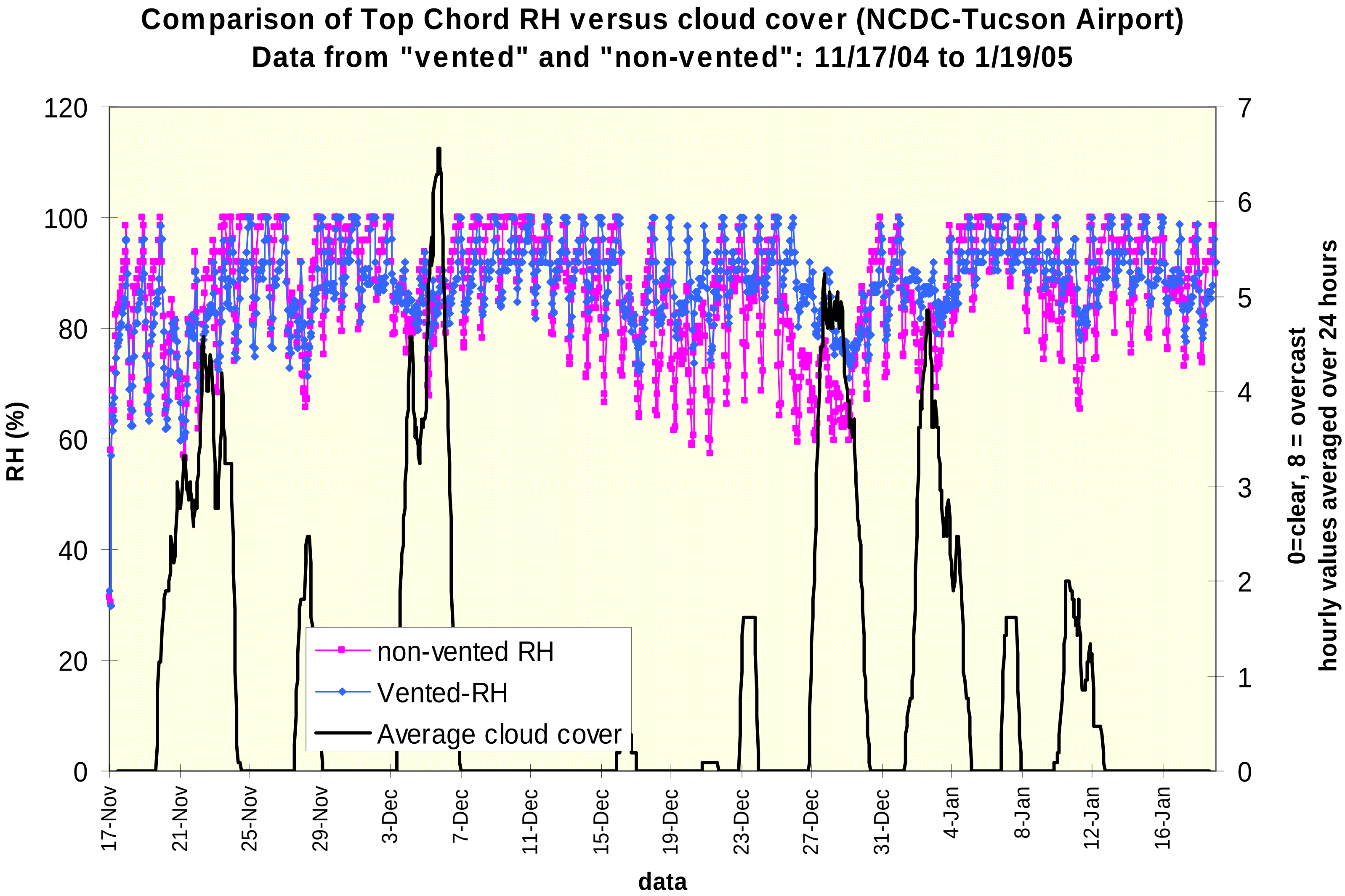


Table 4.2 *Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {WGIII Tables SPM.3, SPM.7}*

Sector	Key mitigation technologies and practices currently commercially available. *Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.*	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; *italics = opportunities*)
Energy Supply {WGIII 4.3, 4.4}	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO_2 from natural gas); *CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics*	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	*May be appropriate to create markets for low-emissions technologies*
Transport {WGIII 5.4}	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; *second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries*	Mandatory fuel economy; biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	*Particularly appropriate for countries that are building up their transportation systems*
Buildings {WGIII 6.5}	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; *integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings*	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	*Attractive for new buildings.* Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	*Government purchasing can expand demand for energy-efficient products*
		Incentives for energy service companies (ESCOs)	*Success factor: Access to third party financing*
Industry	More efficient end-use electrical equipment; heat and power recovery; material	Provision of benchmark information; performance	*May be appropriate to stimulate technology uptake.*

* The **A1** storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B)
* The **A2** storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
* The **B1** storyline and scenario family describes a convergent world with the same **global** population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The **emphasis is on global solutions** to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
* The **B2** storyline and scenario family describes a world in which the emphasis is on **local** solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it **focuses on local and regional levels**.

Comparison between global economic mitigation potential and projected emissions increase in 2030

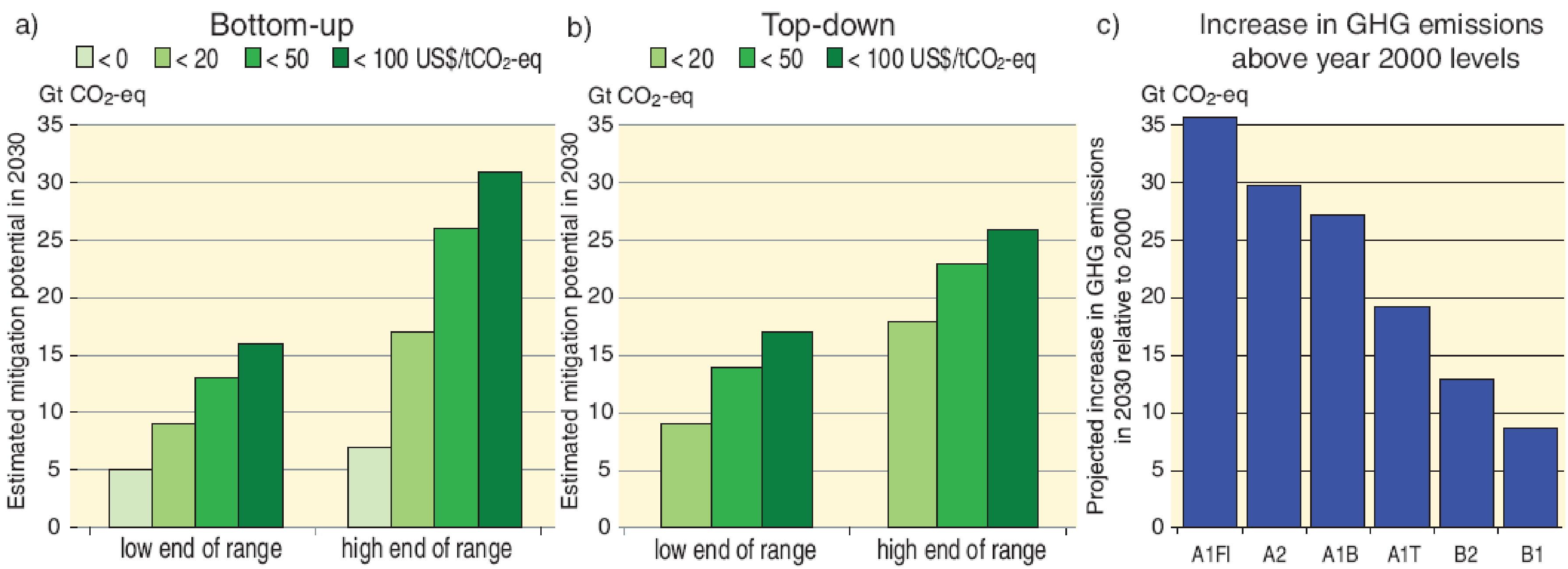


Figure 4.1. Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 $GtCO_2$-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above-ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emissions results. {WGIII Figures SPM.4, SPM.5a, SPM.5b}